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(54) **Turbine rotor-stator leaf seal and related method**

(57) A seal assembly (18) for installation between rotating and stationary components (10, 12) of a machine includes a first plurality of leaf spring segments (20) secured to the stationary component (12) in a cir-

cumferential array surrounding the rotating component, the leaf spring segments (20) each having a radial mounting portion (22) and a substantially axial sealing portion (24), the plurality of leaf spring segments (20) shingled in a circumferential direction.

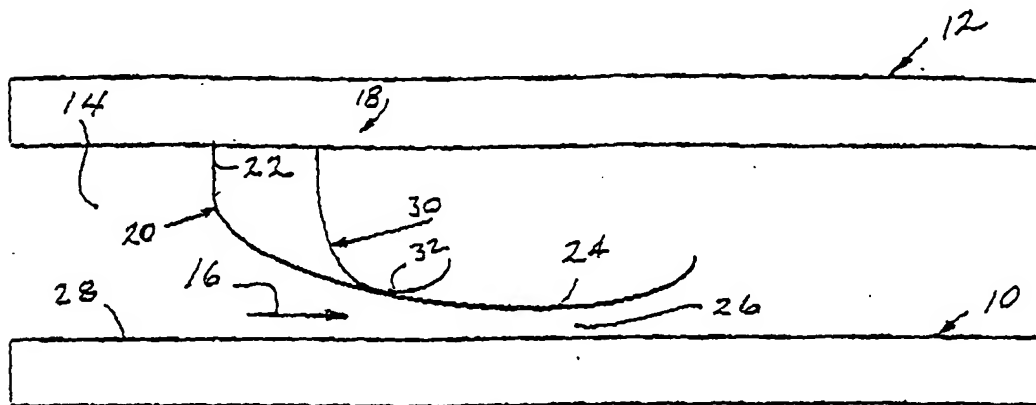


FIG. 1

Description

[0001] This invention relates generally to seals between rotating and stationary machine components and specifically, to a leaf seal assembly between a stator and a turbine rotor.

[0002] Gas turbine operation depends upon the controlled flow of air between rotating and static components. Seals are introduced between these components in order to direct the flow in the desired paths. For example, it may be desirable in some cases to prevent flow in some directions, such as into bearing housings, while in other cases, it may be desirable to direct a controlled amount of flow to actively purge cavities, cool components, and prevent hot flowpath gases from contacting rotor components. Examples of this latter type of seal may be found in the compressor discharge secondary flow circuit and in the paths around the turbine nozzle diaphragms. Establishing a seal that provides a controlled amount of leakage, independent of operating condition, thermal transients, and operating age, has been an ongoing design objective.

[0003] A number of different seal designs have been used in the gas turbine industry. These include: "pumpkin teeth" seals; labyrinth seals; honeycomb seals; and brush seals. All of these designs are intended to provide a "tortuous" path for the air and thus minimize the leakage across them. Table I describes the prior seals, qualitatively comparing them based on certain key features:

TABLE I

FEATURE	PUMPKIN	LABYRINTH	HONEYCOMB	BRUSH
rotor stator contact	no	possible	yes	yes
Deterioration w/ usage	no	if contact	yes	slight
Adapts to transients, operating points	no	no	no	yes
Relative leakage flow	high	lower (because of lower clearances)	lower still	very low
"windage" temperature rise of leakage air	slight	slight	higher	lower
Adapts to casing non-symmetry	no	no	no	yes

[0004] Note that in many applications, some minimum level of air leakage is required to ensure cavity purge flow high enough to preclude contact of rotor structural components with hot gaspath gasses. For this reason, holes allowing air to bypass the seal may be included with brush or honeycomb seals. One difficulty with this approach, however, is that to ensure safe operation, the holes must be sized to provide sufficient flow based a new seal configuration. If the seal later deteriorates, and leaks more flow than when new, the total flow past the seal will be greater than design requirements.

[0005] The present invention utilizes a circumferential array of leaf seals clamped (or otherwise fixed) into the stator component. In the preferred embodiment, the individual leaf seal components or segments each comprise a primary spring and a backing spring, each attached to the stator. The primary spring has an attachment portion and a seal portion that extends generally axially along the rotor, curving toward and then away from the rotor surface in the flow direction. The backing spring also has an attachment portion and a more sharply curved backing portion that engages substantially tangentially the backside of the primary spring. The backing spring serves two purposes:

1. Because of its different curvature and possibly different thickness, the effective stiffness of the two springs together will be non-linear (i.e.: the load-deflection curve will be a curve, not a straight line). This will allow the seal opening, and thus performance, to be optimized over a greater range of operating conditions.

2. Since the two springs will rub against each other, they will serve as friction dampers for each other, preventing vibration and fatigue that might result from aerodynamic instabilities or flutter of the seal.

[0006] The collective array of leaf seal segments are circumferentially overlapped or shingled, requiring the backing springs to be slightly shorter in tangential length than the primary springs. The primary springs are assembled with a slight radial gap relative to the rotor when the machine is not in operation. When the machine is started, a pressure differential develops across the seal, with the higher upstream pressure trying to push the seal open. The force pushing the seal open will be based upon the difference between the total upstream pressure and the total downstream pressure.

As soon as fluid flow past the seal begins, however, the force will drop. This is because the air attains a velocity and the force depends upon the difference between the static upstream and downstream pressures. The downstream velocity will be low, so this static pressure will approximate the total pressure, but the upstream static pressure (opening force) will drop by an amount proportional to the flow rate/velocity.

5 [0007] Since the force opening the seal decreases as the flow rate/velocity increases, and the spring force closing the seal increases with the seal opening, the seal can be designed to allow a controlled "leakage" for any given design point.

[0008] Accordingly, in one aspect, the invention relates to a seal assembly for installation between rotating and stationary components of a machine comprising a first plurality of leaf spring segments secured to the stationary component in a circumferential array surrounding the rotating component, the leaf spring segments each having a radial mounting portion and a substantially axial sealing portion, the plurality of leaf spring segments being shingled in a circumferential direction.

[0009] In another aspect, the invention relates to a turbine rotor and stator arrangement including a leaf spring seal assembly comprising a rotor; a stator surrounding the rotor in radially spaced relation thereto; and a leaf spring seal between the rotor and the stator, the leaf spring seal including a first plurality of leaf spring segments fixed to the stator in a circumferential array about the rotor, the leaf spring segments being circumferentially shingled, and each having a sealing portion defining a predetermined radial gap between the sealing portion and the rotor when the rotor is at rest.

[0010] In still another aspect, the invention relates to a method of sealing a radial gap between a rotor and a stator comprising: a) mounting a first plurality of leaf spring segments to the stator; and b) arranging the first plurality of leaf spring segments in a circumferentially shingled array about the rotor.

20 [0011] An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

25 FIGURE 1 is a schematic side section of leaf seal components between a stator and rotor in accordance with an exemplary embodiment of the invention; and

FIGURE 2 is a schematic end view illustrating the manner in which the leaf seal components are shingled or overlapped in a circumferential direction.

30 [0012] With reference to Figure 1, a rotor 10 and stator 12 are illustrated schematically, with a radial gap 14 therebetween. In a gas turbine environment, airflow in the direction indicated by arrow 16 is controlled by a leaf spring seal assembly 18. The seal assembly 18 comprises individual leaf seal components or segments that are arranged circumferentially about the rotor 10 in a "shingled" or overlapped arrangement best seen in Figure 2. The controlled flow is desired to, for example, actively purge cavities while cooling components and preventing hot flowpath gases from contacting rotor components, e.g., in compressor discharge secondary flow circuits and in paths around the turbine nozzle diaphragms.

35 [0013] Each individual leaf seal component or segment includes a primary leaf spring segment 20 with a mounting portion 22 and a sealing portion 24. The former is attached to the stator 12 by any suitable means (e.g. mechanically clamped or otherwise suitably fixed to the stator), while the sealing portion curves in an axial direction toward then away from the rotor, in a direction of flow, with a minimum radial gap at 26. The primary spring segment 20 is substantially flat in a tangential direction, i.e., as viewed in Figure 2, noting that each leaf seal segment is oriented generally tangentially with respect to the surface 28 of the rotor. The extent of the leaf seal segment in the tangential direction is referred to herein as its tangential length.

40 [0014] Each leaf seal segment also includes a secondary or backing leaf spring segment 30, also attached to the stator 12 in a similar fashion. The backing spring segment 30 is located behind or downstream of the primary spring with a more sharply curved portion 32 engaging the backside of the primary spring in a generally tangential fashion.

[0015] Referring to Figure 2, it will be apparent that in order to overlap or shingle the individual leaf seal assemblies without interference, the backing spring segments 30 will have a shorter tangential length than the primary springs. Nevertheless, the backing spring will be centered on the primary spring as shown in phantom in Figure 2.

50 [0016] Both the primary and secondary spring segments 20, 30 are preferably constructed of spring steel, the specified alloy composition and the thickness of each dependent on the application. The tangential length of the primary springs will depend on the number of segments employed, which is again, application specific. It will be appreciated that the respective effective stiffnesses of spring segments 20, 30 may vary based on different degrees of curvature, different thicknesses and different alloys. This means that the spring stiffness will be non-linear, thus permitting seal opening and thus performance to be optimized over a wide range of operating conditions.

55 [0017] A further advantage to the leaf spring seal consisting of chordal segments shingled over each other is that non-symmetry of the casing can be accommodated, as the different segments may self-adjust to different deflections to maintain a consistent clearance.

[0018] Prior to starting the machine, the primary spring segments 20 should be assembled with a slight gap (at 26) from the rotor surface. At this time, P_1 (pressure upstream of the seal 18) = P_2 (pressure downstream of the seal 18) = P_3 (pressure at the radial gap 26). When the machine is started, P_1 will increase more than will P_2 . In the potential application illustrated (the high pressure packing seal of a particular machine) the pressure across the seal 18 will approach 2:1 at full speed/full load, resulting in choked flow across the seal. At low P_1/P_2 , the flow across the seal assembly 18 will be low, and so the flow velocity will be low, as will the opening force. As P_1/P_2 increases, the Mach number of flow across the seal will also increase, and the ratio of P_1/P_3 will decrease. While P_3 will still be greater than is P_2 , it will not be as much above it as is P_1 , so there will be a reduced force opening the seal. This will be countered by the spring force exerted by both the primary spring segments 20 and backing spring segments 30 closing the gap 26. Thus, the flow will be controlled by P_1/P_2 and the designed opening of the seal at operating conditions. Thus, the seal gap 26 and leakage adapt themselves to the operating conditions. Again, the backing spring segments 30 will preclude any instability as the seal adjusts.

[0019] Typically, the rotor 10 and the stator 12 will have different transient responses to changes in the operating conditions of the machine. At startup, the rotor 10 will rotate in the direction of arrow 34, and may grow rapidly towards the stator 12, due to centrifugal loading. Subsequent to that, the stator 12 will typically respond thermally more quickly than will the rotor 10, and grow away from the rotor, which will subsequently make up some of that gap. As the machine is shut down, the process will be reversed. The pressure ratio across the seal assembly 18 will be largely independent of the thermal transient changes, and so the opening force, and the seal gap 26 will adapt to those changes. As the gap 26 follows the opening forces, however, the spring forces will act to counter those force changes, thus minimizing flow variations.

[0020] The surfaces of the primary spring segments 20 and backing spring segments 30 are all smooth, so there will be very little windage-induced temperature increase. Since there is no contact between the seal assembly 18 and the surface of the rotor 10, there will be little if any deterioration of the seal.

[0021] For completeness, various aspects of the invention are set out in the following numbered clauses:

1. A seal assembly (18) for installation between rotating and stationary components (10, 12) of a machine comprising:

a first plurality of leaf spring segments (20) secured to the stationary component (12) in a circumferential array surrounding the rotating component (10), said leaf spring segments (20) each having a radial mounting portion (22) and a substantially axial sealing portion (24), said plurality of leaf spring segments (20) being shingled in a circumferential direction.

2. The seal assembly of clause 1 and further comprising a second plurality of leaf spring segments (30) downstream of said first plurality of leaf spring segments (20), secured to said stationary component (20) and arranged to engage back surfaces of respective substantially axial sealing portions (24) of said first plurality of leaf spring segments (20).

3. The seal assembly of clause 2 wherein said first and second plurality of leaf spring segments (20, 30) have different respective curvatures.

4. The seal assembly of clause 2 wherein said first and second plurality of leaf spring segments (20, 30) have different thicknesses.

5. The seal assembly of clause 2 wherein said first and second plurality of leaf spring segments (20, 30) have different respective effective stiffness.

6. The seal assembly of clause 2 wherein said first and second plurality of leaf spring segments (20, 30) are constructed of spring steel.

7. The seal assembly of clause 2 wherein said second plurality of leaf spring segments (30) are curved such that they engage said first plurality of leaf spring segments (20) substantially tangentially.

8. The seal assembly of clause 2 wherein there is a radial gap (26) between said first plurality of leaf spring segments (20) and said rotor (10) when said rotor is at rest.

9. A turbine rotor and stator arrangement including a leaf spring seal assembly (18) comprising:

a rotor (10);

a stator (12) surrounding said rotor in radially spaced relation thereto; and

5 a leaf spring seal assembly (18) between said rotor (10) and said stator (12), said leaf spring seal assembly including a first plurality of leaf spring segments (20) fixed to said stator (12) in a circumferential array about said rotor (10), said leaf spring segments (20) being circumferentially shingled, and each having a sealing portion (24) defining a predetermined radial gap (26) between the sealing portion (24) and the rotor (10) when the rotor is at rest.

10 10. The arrangement of clause 9 and further comprising a second plurality of leaf spring segments (30) downstream of said first plurality of leaf spring segments (20), secured to said stationary component (12) and arranged to engage respective substantially axial sealing portions (24) of said first plurality of leaf spring segments (20).

15 11. The arrangement of clause 10 wherein said first and second plurality of leaf spring segments have different respective curvatures.

20 12. The arrangement of clause 10 wherein said first and second plurality of leaf spring segments (20, 30) have different thicknesses.

13. The arrangement of clause 10 wherein said first and second plurality of spring segments (20, 30) have different respective effective stiffnesses.

25 14. The arrangement of clause 10 wherein said first and second plurality of leaf spring segments (20, 30) are constructed of spring steel.

15. The arrangement of clause 10 wherein said second plurality of leaf spring segments (30) are curved such that they engage said first plurality of leaf spring segments (20) substantially tangentially.

30 16. The arrangement of clause 10 wherein said second plurality of leaf spring segments (30) engage back sides of said first plurality of leaf springs (20).

17. A method of sealing a radial gap between a rotor (10) and a stator (12) comprising:

35 a.) mounting a first plurality of leaf spring segments (20) to said stator; and

b.) arranging said first plurality of leaf spring segments (20) in a circumferentially shingled array about said rotor (10).

40 18. The method of clause 17 and further including mounting a second plurality of leaf spring segments (30) behind respective ones of said first plurality of leaf spring segments (20), with said second plurality of leaf spring segments engaging said first plurality of leaf spring segments.

45 19. The method of clause 18 wherein said first plurality of leaf spring segments (20) each have a sealing face and a backside, and wherein said second plurality of leaf spring segments (30) engage the backside of said first plurality of leaf spring segments.

50 20. The method of clause 18 wherein, during step b), radial gaps (26) are maintained between said rotor (10) and said first plurality of leaf spring segments (20).

Claims

55 1. A seal assembly (18) for installation between rotating and stationary components (10, 12) of a machine comprising:

a first plurality of leaf spring segments (20) secured to the stationary component (12) in a circumferential array surrounding the rotating component (10), said leaf spring segments (20) each having a radial mounting portion (22) and a substantially axial sealing portion (24), said plurality of leaf spring segments (20) being shingled in

a circumferential direction.

2. The seal assembly of claim 1 and further comprising a second plurality of leaf spring segments (30) downstream of said first plurality of leaf spring segments (20), secured to said stationary component (20) and arranged to engage back surfaces of respective substantially axial sealing portions (24) of said first plurality of leaf spring segments (20).
3. The seal assembly of claim 2 wherein said first and second plurality of leaf spring segments (20, 30) have different respective curvatures.
4. The seal assembly of claim 2 wherein said first and second plurality of leaf spring segments (20, 30) have different thicknesses.
5. The seal assembly of claim 2 wherein said first and second plurality of leaf spring segments (20, 30) have different respective effective stiffness.
6. The seal assembly of claim 2 wherein said first and second plurality of leaf spring segments (20, 30) are constructed of spring steel.
7. A turbine rotor and stator arrangement including a leaf spring seal assembly (18) comprising:
 - a rotor (10);
 - a stator (12) surrounding said rotor in radially spaced relation thereto; and
 - a leaf spring seal assembly (18) between said rotor (10) and said stator (12), said leaf spring seal assembly including a first plurality of leaf spring segments (20) fixed to said stator (12) in a circumferential array about said rotor (10), said leaf spring segments (20) being circumferentially shingled, and each having a sealing portion (24) defining a predetermined radial gap (26) between the sealing portion (24) and the rotor (10) when the rotor is at rest.
8. The arrangement of claim 7 and further comprising a second plurality of leaf spring segments (30) downstream of said first plurality of leaf spring segments (20), secured to said stationary component (12) and arranged to engage respective substantially axial sealing portions (24) of said first plurality of leaf spring segments (20).
9. The arrangement of claim 8 wherein said first and second plurality of leaf spring segments have different respective curvatures.
10. A method of sealing a radial gap between a rotor (10) and a stator (12) comprising:
 - a.) mounting a first plurality of leaf spring segments (20) to said stator; and
 - b.) arranging said first plurality of leaf spring segments (20) in a circumferentially shingled array about said rotor (10).

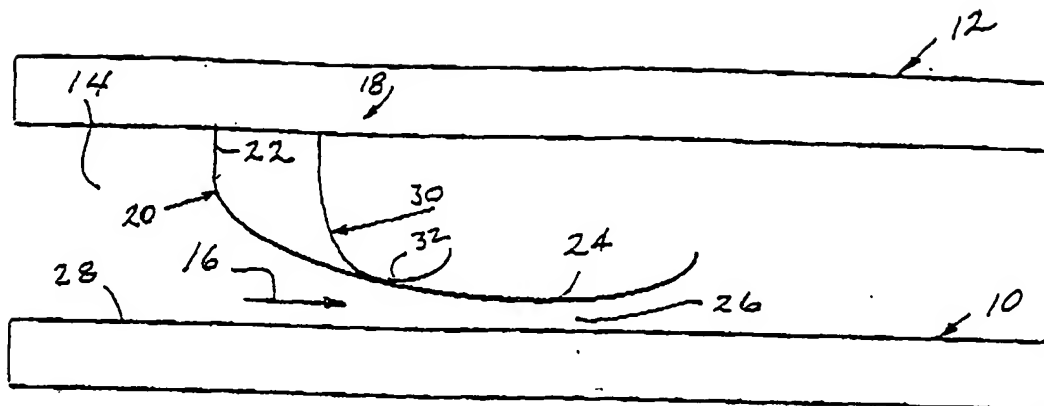


FIG. 1

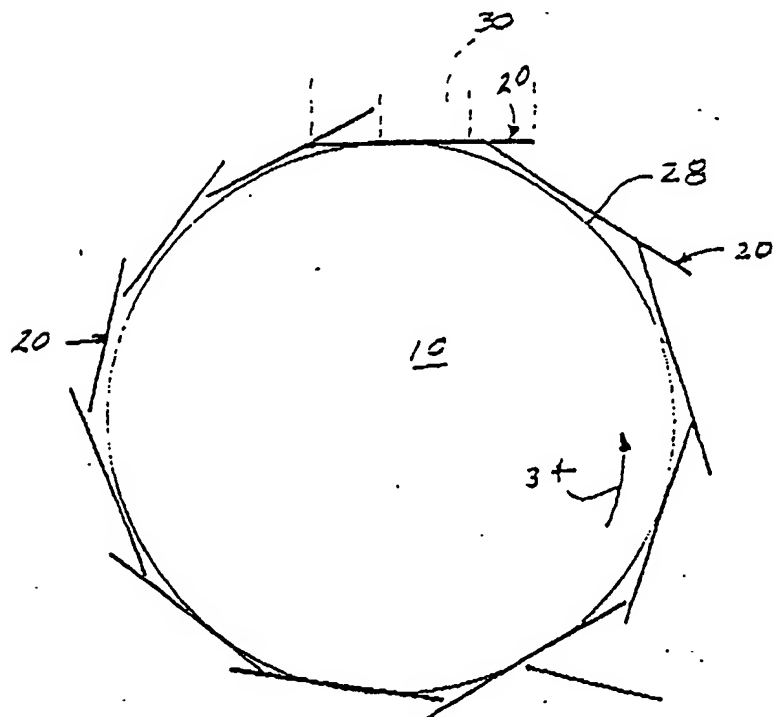


FIG. 2